The Geology of the Bungonia-Windellama Area, New South Wales

B. G. JONES, C. G. HALL, A. J. WRIGHT and P. F. CARR

JONES, B. G., HALL, C. G., WRIGHT, A. J., & CARR, P. F. The geology of the Bungonia-Windellama area, New South Wales. *Proc. Linn. Soc. N.S.W.* 108 (4) (1985) 1986: 267-286.

In the Windellama district of New South Wales the basement consists of Late Ordovician flysch, the Tallong Beds. These strata are overlain unconformably by the diachronous Tangerang Formation in which Early Devonian fossils occur just above the base. Low in the formation quartz-rich detritus and carbonate units are developed; higher levels are volcanogenic. The Brooklyn Conglomerate Member is proposed for a thin (60m) conglomeratic unit which immediately overlies the Tallong Beds in the southern part of the region. Palaeocurrents in the basal Brooklyn Conglomerate Member were from the south and west (052°) compared with an overall northerly trend (005°) for the whole Tangerang Formation.

Six plutons of the Marulan Batholith occur in the district, including two plutons named herein as the Torwood Granodiorite and the Bogungra Microtonalite. Deformation of the Tangerang Formation was presumably associated with the Bowning Orogeny, just prior to the intrusion of the Marulan Batholith. Late Devonian strata unconformably overlie the Tangerang Formation and the Marulan Batholith.

Invertebrate fossils from the Tangerang Formation are illustrated for the first time; these are the trilobites *Ananaspis ekphyma* sp. nov., cf. *Lioharpes* sp., *?Crotalocephalus* spp., an indeterminate proetid, and *?Acanthopyge (Lobopyge)* sp.; and the tabulate coral *Pleurodictyum* sp. These are Early Devonian (Lochkovian) faunas similar to those developed in the upper part of the Bungonia Limestone which underlies the Tangerang Formation south of Windellama.

B. G. Jones, C. G. Hall, A. J. Wright and P. F. Carr, Department of Geology, University of Wollongong, P.O. Box 1144, Wollongong, Australia 2500; *manuscript received 20 November 1985, accepted for publication in revised form 19 February 1986.*

INTRODUCTION

The Bungonia-Windellama area is situated on the exposed eastern margin of the Lachlan Fold Belt of New South Wales (Fig. 1). The geology of the region is typical of much of the Fold Belt and consists of Ordovician flysch overlain by Silurian and Early Devonian dacitic and rhyolitic volcanic units, tuffaceous sedimentary rocks and limestone. These Palaeozoic sequences were intruded by Devonian granitoids of the Marulan Batholith and in places are unconformably overlain by Late Devonian shallow marine and terrestrial deposits.

The regional stratigraphy of the Bungonia-Windellama region has been investigated by many authors. Woolnough (1909) carried out the first detailed geological study and further references to the regional geology were made by Naylor (1935, 1936, 1950) and Garretty (1937). Limestones of the region have been studied by numerous authors including Carne and Jones (1919), Pratt (1964), Pickett (1970, 1972), Ellis *et al.* (1972), Mawson (1975), Carr *et al.* (1980), Carr *et al.* (1981) and Jones *et al.* (1981). Parts of the Marulan Batholith have been described by Osborne (1931, 1949), Naylor (1939), Osborne and Lovering (1953) and Carr *et al.* (1981), and the batholith has been dated by Carr *et al.* (1980).

Brunker and Offenberg (1968) mapped the region on a 1:250,000 scale. They suggested that the sequence in the Bungonia-Windellama area consists of Ordovician sedimentary rocks conformably overlain by undifferentiated Ordovician-Silurian sedimentary rocks, which were intruded in the Middle Devonian by granite and tonalite porphyry, and capped by Tertiary basalt and laterite. Mawson (1975) conducted

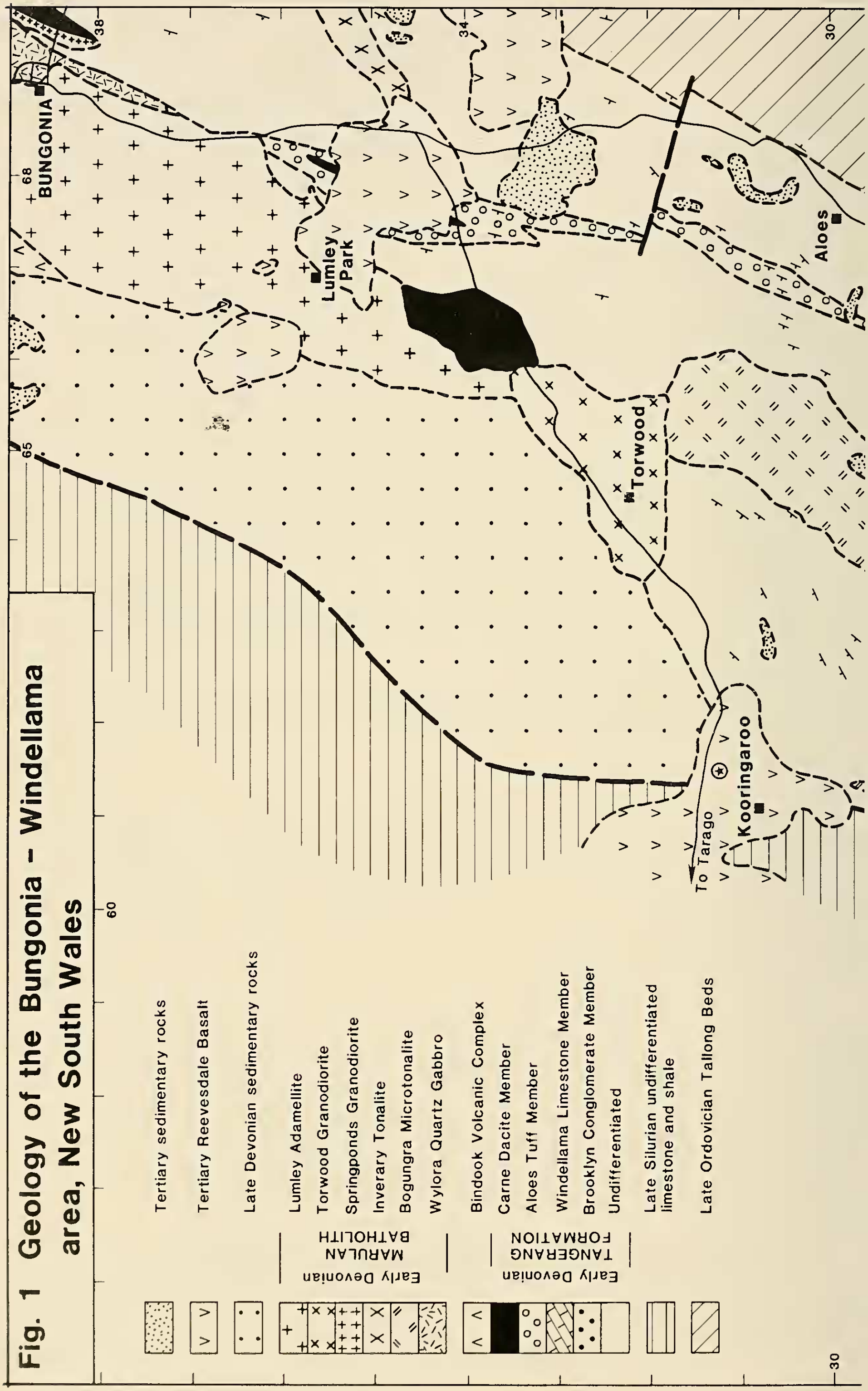
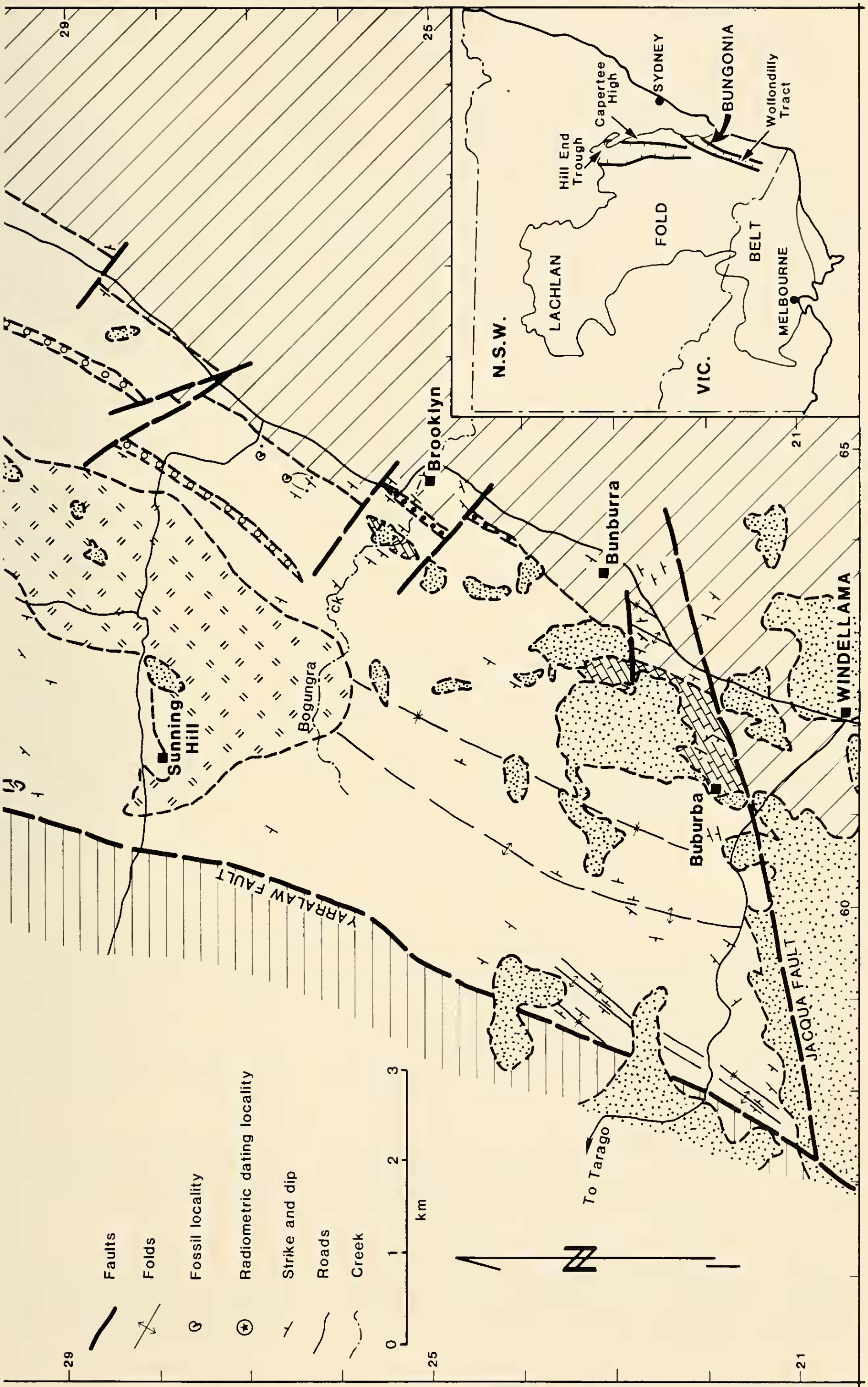


Fig. 1 Geology of the Bungonia - Windellama area, New South Wales


Faults
Folds
Fossil locality
Radiometric dating locality
Strike and dip
Roads
Creek
km
0
1
2
3
To Tarago
YARRALAW FAULT
JACQUA FAULT
Sunning Hill
Bogungra
ck
Brooklyn
Bunburra
Buburba
WINDELLAMA
29
25
21
65
60
N.S.W.
VIC.
LACHLAN
FOLD
BELT
SYDNEY
BUNGONIA
MELBOURNE
Capertee High
Hill End Trough
Wollondilly Tract

geological investigations in the Windellama area and concluded that the sequence consists of approximately 1700m of Early Devonian carbonate and terrigenous sedimentary rocks downfaulted into rocks '. . . at least in part of Late Silurian age' (Mawson, 1975: 29). This sequence is overlain by numerous Cainozoic units.

Carr *et al.* (1981) mapped the area north and east of Bungonia which consists of Late Ordovician sandstone and shale unconformably overlain by the Late Silurian to Early Devonian Bungonia Limestone. This latter formation is conformably overlain at Bungonia by the Tangerang Formation — a sequence of shallow marine to terrestrial limestone and volcaniclastic sandstone interbedded with tuff and lensoidal dacite flows (Jones *et al.*, 1984). The Marulan Batholith was emplaced during the Early Devonian (Carr *et al.*, 1980), eroded subsequently and covered by the shallow marine Late Devonian succession. The Ordovician to Devonian rocks are unconformably overlain by erosional remnants of Permian and post-Permian sedimentary and volcanic rocks.

The detailed geology of the area between Windellama and Bungonia has not been published previously. The aim of the present paper is to document the geology of this area, to describe a new species of the trilobite *Ananaspis*, to determine the relationship between the units at Windellama and Bungonia, and to ascertain how these sequences fit into the broader regional pattern.

Rock specimens are housed in the Department of Geology, University of Wollongong, and the fossils are housed in the Australian Museum, Sydney. Grid references refer to the Kooringaroo 1:25,000 topographic sheet (8828-II-S, First Edition, 1971).

TALLONG BEDS

The Late Ordovician Tallong Beds (Wass and Gould, 1969) form an extensive outcrop belt from Windellama northwards at least as far as Marulan. The Tallong Beds are composed of interbedded quartz-rich arenite, shale, slate and phyllite, with less common chert interbeds (Table 1). Poor outcrop exposure and tight to isoclinal folding of the Tallong Beds renders the determination of the stratigraphy of this sequence difficult.

TABLE 1

Petrography of the Tallong Beds

Lithology	Composition	Other Features
Quartz-rich arenite	Fine-grained, dark to mid grey, poorly to moderately sorted, immature sublitharenite. Framework grains (0.03–0.7 mm) are subangular to rounded, most are subrounded. Quartz (70–80%), feldspar (0–2%), siltstone and chert rock fragments (1–4%), muscovite (1–2%), minor amphibole, epidote, tourmaline, zircon, rutile and Fe-Ti oxides. Minor quartz cement. Muscovite flakes are parallel to bedding. Matrix (15–25%) of quartz, sericite, clay and Fe oxides.	Most abundant in southeast. Beds mainly massive and 10–30 cm thick (range 1–120 cm). Bouma sequences recognised in many beds — include erosional base, flute marks, load casts, graded beds, flat- and cross-laminated beds, contorted beds. Arenite is interbedded with thin shale beds.
Chert	Aphanitic pale grey to greenish grey chert (80–90%) with scattered detrital quartz (5–10%), as subangular to sub-rounded grains up to 0.25 mm, and muscovite (2–5%). Rare tourmaline, Fe-Ti oxides, rutile, amphibole and clay. Muscovite flakes are aligned parallel to bedding. One sample (R9495) contains about 3% slightly recrystallised Radiolaria.	Common near margin with Tangerang Formation. Beds 1–25 cm thick, mainly massive, strongly jointed and interbedded with thin shale laminae. Cut by numerous small quartz veins.
Shale, slate and phyllite	Blue-grey very fine-grained chloritic and sericitic clays. Detrital grains (5%) consist of quartz, muscovite (flakes up to 0.1 mm) and Fe-Ti oxides.	Occurs as interbeds in the arenite and chert and as distinct lenses. Cleavage subparallel to bedding on fold limbs.

In the northeastern part of the area the Tallong Beds crop out as a thinly-bedded slate-chert unit which exhibits large-scale isoclinal folds and probably represents deposition in quiet water with reducing conditions at the sediment-water interface. The Tallong Beds cropping out south of 'Bunburra' (Fig. 1) are represented by a well-bedded arenite-slate sequence. The thickness of individual beds is between 1cm and 1.2m. Large- and small-scale tight to isoclinal folds are common in this sequence, particularly in the shale interbeds which display prominent axial hinge thickening and weak to moderate bedding plane cleavage. Some localities (e.g. GR 631226) show complex small-scale deformation of the shale interbeds. Sedimentary structures are common in the arenite interbeds and include flute marks, graded bedding, slumped and contorted bedding, ripple cross-bedding, and ball and pillow structures. Bouma sequences at GR 628277 and the orientation of flute marks in the arenite at GR 631227 indicate that the beds are the right way up and that palaeocurrents were from the south. It is inferred that this interbedded arenite-slate sequence represents a distal flysch sedimentary accumulation.

The only fauna identified in the Tallong Beds in this area are Radiolaria in a greenish-grey chert at GR 658277 (sample R9495). However, the Tallong Beds in the Bungonia area are known to be of Late Ordovician age (Sherrard, 1949, 1954, 1962; Sherwin, 1972; Carr *et al.*, 1981) and equivalent rocks on the Braidwood 1:100,000 Geological Sheet consist of undifferentiated greywacke-slate sequences containing some Late Ordovician graptolitic black slate (Felton and Huleatt, 1977).

Late Silurian Beds

Unnamed Late Silurian limestone and shale crop out in the southern part of the area west of the Yarralaw Fault (Fig. 1). The limestone outcrops were mapped by Mawson (1975) and consist of grey, massive to weakly bedded, westerly dipping, partly dolomitized limestone containing a Late Silurian fauna of brachiopods, corals, nautiloids, gastropods and stromatoporoids. Farther north, unfossiliferous limestone occurs only as scree (e.g. GR 611301) and the most common lithology is pale buff to brown ferruginized shale. This limestone-shale unit was probably deposited in a shallow marine environment as a lateral equivalent of the Late Silurian portion of the Bungonia Limestone.

Tangerang Formation

The Tangerang Formation between Bungonia and Windellama consists predominantly of an undifferentiated sequence of sublitharenite, volcaniclastic arenite and fine and coarse tuff. Lithological variations within this sequence primarily represent lateral facies changes and the distribution and petrography of these major lithologies are summarized below.

Clastic arenite. The basal sequence (approximately 550m) of the Tangerang Formation is characterized by sublitharenite but significant variations in composition occur (Table 2, Fig. 2). In general the sandstone from the lower levels of the formation has a finer grain size and is composed dominantly of detrital quartz and sedimentary lithic fragments with less common feldspar, and is classified as sedarenite or subsedarenite. As the stratigraphic sequence is ascended the sandstone becomes coarser grained, has a much greater feldspar content, contains small amounts of volcanic quartz and is classified as lithic arkose or feldspathic litharenite. This transition is not uniform throughout the area and scattered interbeds of volcaniclastic arenite are present at most levels.

TABLE 2

Petrography of the undifferentiated Tangerang Formation

Lithology	Composition	Other Features
Clastic arenite	Very fine- to coarse-grained (0.08–0.6 mm), moderately to poorly sorted, immature. Angular to rounded quartz, sedimentary rock fragments (siltstone, quartzite, chert), metamorphic rock fragments, minor plagioclase (An_{30-36}) and rare devitrified volcanic rock fragments. Accessory minerals include zircon, Fe-Ti oxides and tourmaline. Chert, microcrystalline quartz and clay matrix with secondary calcite and sericite.	Massive to well-bedded with beds ranging from 3–40 cm thick. Rare argillaceous interbeds present. Ripple cross-beds, symmetrical and asymmetrical current ripple marks. Fossils rare in the north (crinoid ossicles, bryozoans) but trilobites and corals are abundant in the south. A few interbeds of volcaniclastic arenite are present and become more abundant with increasing stratigraphic height.
Volcaniclastic arenite	Medium- to very coarse-grained (0.1–1.4 mm), poorly sorted, immature. Subangular to rounded detrital and volcanic quartz, K-feldspar (orthoclase), plagioclase (An_{22-46}), devitrified volcanic rock fragments, relict glass shards, sedimentary rock fragments (chert, siltstone, fine micaceous sandstone) and rare metaquartzite. Accessory minerals include muscovite, Fe-Ti oxides, zircon, tourmaline, amphibole, calcite and rare pyrite and biogenic detritus.	Generally moderately to well-bedded with beds ranging from 5–60 cm thick. Sedimentary structures include ripple and large-scale tabular cross-beds. Fossils are rare and fragmentary.
Coarse tuff and lapilli	Medium- to very coarse-grained (0.2–2.5 mm), poorly sorted, immature. Detrital and volcanic quartz, orthoclase, plagioclase (An_{35-50}), volcanic rock fragments (glass shards and aphanitic ejectamenta), sedimentary and metamorphic lithic fragments. Accessory uralite, biotite, pyrite, tourmaline and Fe-Ti oxides. Chert, uralite and chlorite matrix.	Most abundant in the upper part of the formation in the 'Torwood'-'Kooringaroo' area. Moderately to well-bedded. Beds ranging from 5–50 cm thick — occasionally massive. Ripple cross-bedding and large-scale tabular cross-bedding common. Rare fragmentary marine fossils (crinoids).
Fine tuff	Poorly to moderately sorted, fine- to medium-grained (0.05–0.3 mm), immature. Detrital and volcanic quartz, Fe oxides, relict glass shards and rare feldspar in a chert matrix.	Well-bedded, beds ranging from 2–50 mm in thickness. Alternating reworked and massive microbeds. Current ripple cross-bedding. No fossils. Similar distribution to coarse tuff.

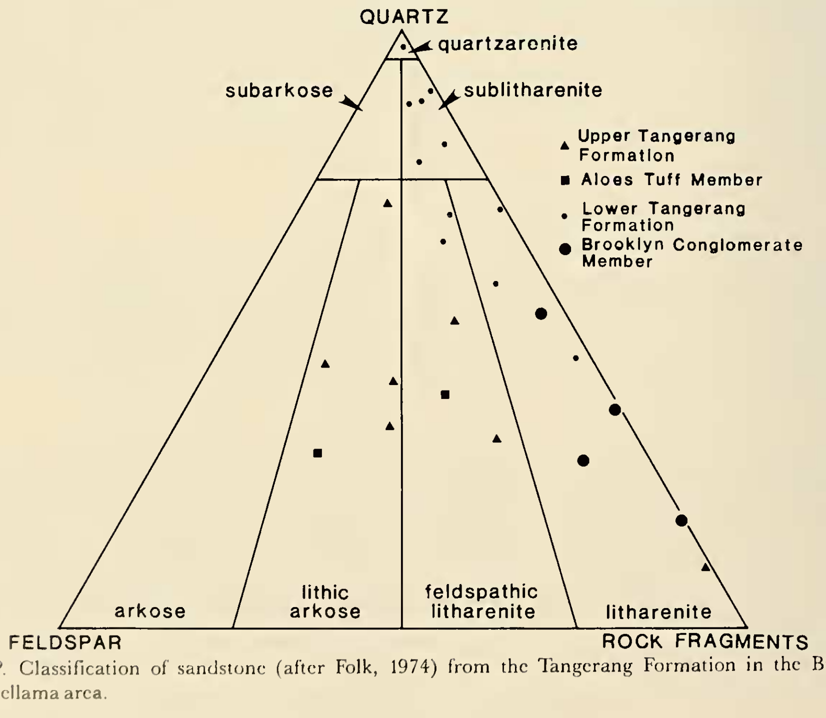


Fig. 2. Classification of sandstone (after Folk, 1974) from the Tangerang Formation in the Bungonia-Windellama area.

Volcaniclastic arenite. This lithology does not crop out as a distinct mappable unit, but rather as lenses within other sedimentary rocks of the Tangerang Formation. Beds range from 2cm to 50cm in thickness and may be internally laminated or massive. The volcaniclastic arenite is composed of detrital and volcanic quartz, plagioclase, K-feldspar and lithic fragments, with accessory Fe-Ti oxides, mica, tourmaline and rare zircon (Table 2) and ranges from lithic arkose to litharenite. Rocks from higher parts of the sequence are relatively enriched in volcanic quartz and volcanic lithic fragments. Some samples (e.g. R9480) contain abundant devitrified volcanic detritus and relict glass shards. The detrital volcanic component of the sandstone decreases in abundance south of 'Sunning Hill'. In this area the sandstone is commonly enriched in sedimentary lithic components, thus indicating that the source for the volcanic detritus was to the north.

Coarse and fine tuff. A distinctive lens of interbedded coarse and fine tuff with minor volcaniclastic arenite occurs in the 'Torwood'–'Kooringaroo' area and is up to 130m thick. Its northeasterly trend is attributed to displacement associated with the intrusion of the Marulan Batholith. The tuff shows no evidence of welding or fiamme but rather it is moderately- to well-bedded, containing some large-scale tabular cross-beds and crinoid ossicles. Relict glass shards and aphanitic volcanic fragments are common (Table 2) and the rocks probably represent primary and reworked ashfall tuffs. These tuffs are mineralogically and texturally very similar to the Aloes Tuff Member. A unit of coarse-grained volcaniclastic arenite and minor tuff occurs along the anticlinal axis in the southern part of the area. This may represent a unit equivalent to, but more extensively reworked than, the tuff near 'Torwood'.

Three lensoidal members were described from the Tangerang Formation by Jones *et al.* (1984) — the Windellama Limestone, Carne Dacite and Aloes Tuff Members. A distinctive basal conglomerate can be recognized in part of the Bungonia-Windellama area and is defined here as a fourth member — the Brooklyn Conglomerate Member.

BROOKLYN CONGLOMERATE MEMBER (new name)

The Brooklyn Conglomerate Member is proposed for a sequence of interbedded conglomerate and medium- to coarse-grained sandstone that crops out immediately above the Tallong Beds at the type locality (GR 645253) in Bogungra Creek. The member is named after the property 'Brooklyn' (GR 644252) and the unit can be seen unconformably overlying folded Ordovician flysch in a cutting on the Bungonia-Windellama road near 'Brooklyn' (GR 646254, Fig. 3). A thin band of conglomerate

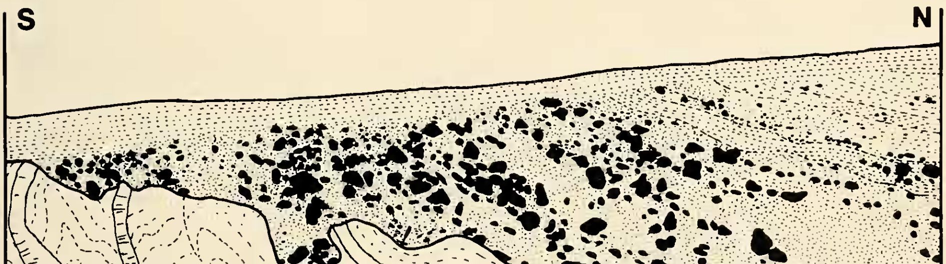


Fig. 3. Sketch of the cutting on the Bungonia-Windellama road near Bogungra Creek showing the unconformable contact between the Late Ordovician Tallong Beds and the overlying Early Devonian Brooklyn Conglomerate Member of the Tangerang Formation (drawn from photographs). The cutting is very weathered and part of the conglomerate matrix may represent clay derived from the overlying soil. The conglomeratic sandstone at the northern end of the outcrop shows faint cross-bedding.

also crops out about 1km farther south at GR 641242. The Brooklyn Conglomerate Member lenses out rapidly north and south of 'Brooklyn' and has a maximum thickness of 60m.

The unit is moderately- to well-bedded and displays a uniform westerly dip of 30° to 40°. Medium- to coarse-grained sandstone interdigitates with beds containing angular and rounded clasts of quartzite, micaceous sandstone, chert and siltstone ranging from 2cm to 60cm in diameter. The clasts are set in a fine-grained quartz and

TABLE 3

Petrography of Members of the Tangerang Formation

Member	Lithology	Composition	Other Features
Brooklyn Conglomerate Member	Polymictic conglomerate, sandstone	Medium- to very coarse-grained (0.1 mm to 60 cm clasts), very poorly sorted, immature. Angular and rounded clasts of quartzite, chert, siltstone and fine micaceous sandstone in a matrix of chert, fine-grained quartz and Fe oxides. Interbedded arenite with 0.1–1.3 mm grain size.	Moderately to poorly bedded; beds range from 10–80+ cm in thickness. Rare fragmentary marine fossils present (crinoid ossicles and corals). Grades to medium-grained cross-bedded sandstone.
Windellama Limestone Member	Limestone (biopelmicrite, biomicrite, biosparite), rare shale	Fine- to very fine-grained (<0.01–0.1 mm), moderately to well-sorted, wackestone texture. Pellets common in south, fossil fragments scattered throughout, micrite most abundant in south and is partly replaced northwards by spar calcite cement. Accessory minerals include quartz, pyrite and clay.	Well-bedded; beds range from 5–30 cm in thickness. Richly fossiliferous (rugose and tabulate corals, brachiopods, nautiloids, conodonts). Geopetal structures are common in the northern lenses.
Aloes Tuff Member	Coarse tuff and lapilli	Bimodal; fine- to coarse-grained (0.02–2.5 mm), poorly sorted, immature. Detrital and volcanic quartz, K-feldspar, plagioclase (An_{31-45}), volcanic rock fragments (aphanitic ejectamenta and pumice), relict glass shards, sedimentary rock fragments (chert, siltstone, fine sandstone) and metaquartzite. Accessory Fe-Ti oxides, zircon, tourmaline and rutile. Matrix of chert and clay.	Moderately to well-bedded in the south with beds ranging from 1–25 cm in thickness. Ripple cross-bedding and rare large-scale tabular cross-bedding. No fossils. In the north beds are up to 2 m thick and massive to weakly laminated. Accretionary lapilli are present in some beds with flattened lapilli occurring towards the base of each bed.
	Fine tuff	Very fine-grained (0.01–0.25 mm), moderately sorted, immature. Detrital and volcanic quartz, K-feldspar, plagioclase (An_{31-40}) and relict glass shards. Accessory zircon, hornblende, pyrite and rutile. Matrix of chert.	Well-bedded; beds ranging from 2–80 mm in thickness. Small-scale ripple cross-bedding. Rare crinoid ossicles.
Carne Dacite Member	Porphyritic hornblende dacite	Phenocrysts of embayed quartz, greenish plagioclase (An_{48-52}), hornblende and hypersthene. Very fine-grained groundmass of quartz, plagioclase, K-feldspar and minor hornblende, hypersthene, biotite and Fe-Ti oxides.	Extensively altered with common chlorite, sericite and kaolinite as devitrification products of the glassy groundmass.

clay matrix which also contains a few fossil fragments. The petrography of this unit is summarized in Table 3 and Figure 2. Analysis of cross-bed orientations in the arenite units indicates that the Brooklyn Conglomerate Member has a northeastward (052°) palaeocurrent trend.

The boulder conglomerate was probably deposited in a very shallow marine environment at the mouth of a large stream eroding the Late Ordovician basement in the area. Supporting evidence for this proposal includes:

i) the relatively restricted lateral occurrence of the unit;
ii) the restriction of large angular blocks to the base of the conglomerate;
iii) the polymictic nature of the conglomerate;
iv) the abundance of rounded, abraded clasts; and
v) the presence of fragmentary crinoids and corals.

WINDELLAMA LIMESTONE MEMBER

The main outcrops of the Windellama Limestone Member (Pickett and Huleatt, 1971; redefined by Jones *et al.*, 1984) southwest of 'Bunburra' have been described in detail by Mawson (1975) who subdivided the limestone into three units. The lowest unit is poorly-bedded and dolomitic, the middle unit is a black well-bedded, partly silicified pelletal micritic limestone and the highest unit is a massive dark grey micritic limestone. Fossils occur throughout the member but are most abundant in the middle unit. Lochkovian (earliest Devonian) conodonts were reported from this member by Mawson (1975); further faunal studies have not been attempted in the present study.

Lenses of limestone which are lithologically and faunally similar to the middle unit at Windellama occur near 'Brooklyn' (GR 641254) and 'Aloes' (GR 673303 and GR 683314). These lenses are interbedded within the arenitic strata of the Tangerang Formation and their petrography and sedimentary features are summarized in Table 3.

The thickness of the Windellama Limestone Member ranges from 285+m in the type section at GR 626230 to 25+m at the northernmost outcrop. The limestone was deposited in a shallow marine environment with the greatest water depths (about 50m) being attained during the deposition of the middle unit (Mawson, 1975).

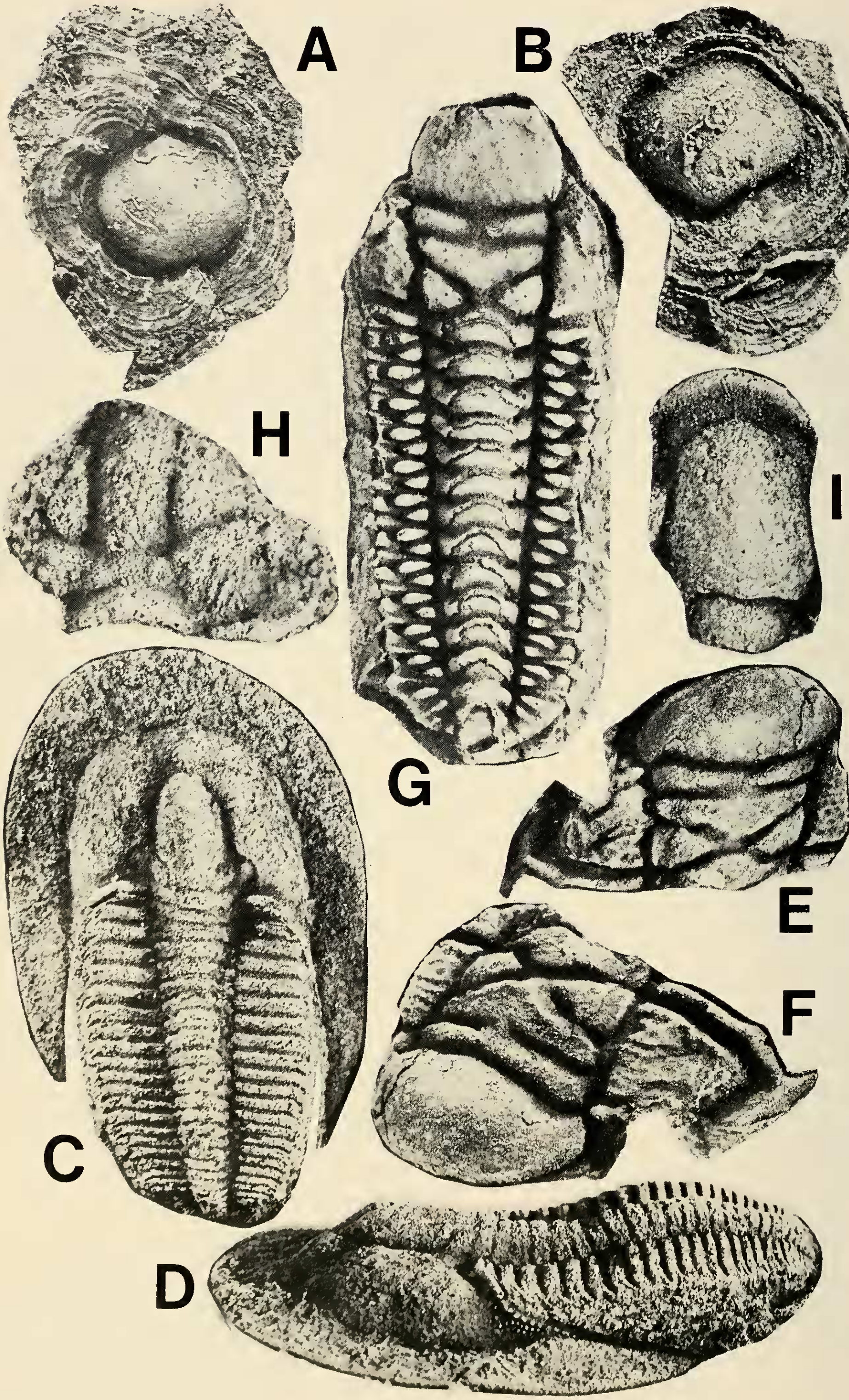
ALOES TUFF MEMBER

The Aloes Tuff Member, defined by Jones *et al.* (1984) is confined to the 'Lumley Park'–'Brooklyn' area where it occurs as an elongate lens approximately 550m above the base of the Tangerang Formation. The unit is thickest near 'Lumley Park' (230m) and it decreases in thickness southwards until it lenses out into reworked volcaniclastic sandstone in the 'Brooklyn' area.

In the 'Lumley Park' area the Aloes Tuff Member consists of thick (up to 2m), massive- to weakly-bedded, fine and coarse tuff with several beds of accretionary lapilli (e.g. GR 676337) and one outcrop of volcanogenic breccia. Occasional interbeds of coarse tuff containing scattered small (<2cm) fiamme represent the welded parts of ashflows and led Jones *et al.* (1984) to postulate that this part of the Aloes Tuff Member accumulated on the flanks of a subaerial volcano. Farther south the Aloes Tuff Member is well-bedded on a millimetre scale, the proportion of fine tuff increases and the unit shows increasing evidence of reworking in a marine environment as indicated by the presence of rare crinoid ossicles. The petrography and sedimentary features of the Aloes Tuff Member are summarized in Table 3 and Figure 2.

CARNE DACITE MEMBER

Three outcrops of dacite occur within the study area and all form part of the Carne Dacite Member as defined by Jones *et al.* (1984). The outcrop just east of Bungonia was previously described as the western hornblende dacite (Carr *et al.*, 1981). The second dacite occurring 2km northeast of 'Torwood' is pale grey, porphyritic and contains at least one interbed of coarse tuff and volcanogenic breccia (GR 663337); the dacite shows an abrupt southward termination into units of coarse tuff and volcaniclastic arenite


A
B
H
I
G
E
F
C
D

while its northward extent has been truncated by plutons of the Marulan Batholith. The limited extent of the dacite suggests that it has a domal form with a thickness of at least 410m. The third dacite occurs as a thin lens (maximum thickness of 40m) within the Aloes Tuff Member east and southeast of 'Lumley Park'. The petrography of these dacite units is given in Table 3.

FAUNA AND AGE

Invertebrate fossils from clastic strata occur at a number of localities mainly in the lower part of the Tangerang Formation. In most cases, the fossils are poorly preserved, tectonically deformed and silicified.

Useful faunas were obtained from three locations in the east-central part of the area (Fig. 1, GR 652268, 648262 and 647263). These faunas include: *Pleurodictyum* (Fig. 4**A-B**) and other indeterminate tabulate corals and solitary tetracorals; indeterminate fenestellid bryozoans and rare gastropods; the brachiopods cf. *Salopina* and cf. *Nucleospira*; and the trilobites cf. *Lioharpes* (Fig. 4**C-D**), *?Crotalocephalus* (Fig. 4**E-G**), *Ananaspis ekphyma* sp. nov. (see Appendix, Fig. 6**A-K**), *?Acanthopyge (Lobopyge)* (Fig. 4**H**), and proetid (Fig. 4**I**), scutelluid and odontopleurid fragments. Almost all shells are disarticulated, but show little evidence of abrasion due to transportation. Several *Pleurodictyum* specimens encrust cf. *Nucleospira* shells. These shells also bear a pre-existing epifauna which attests to a low-energy environment with intermittent sedimentation (Fig. 4**A-B**).

The three main faunal localities occur at a stratigraphic level approximating to that of the limestone lenses near 'Brooklyn' and 'Aloes' (Fig. 1). Hence, they would correlate with the middle part of the Windellama Limestone Member, for which a Lochkovian (Early Devonian) age was established by Mawson (1975) on the basis of conodonts. Similarity of the fauna north of 'Brooklyn' with Lochkovian faunas from the Bungonia Limestone (largely unpublished data) and Heathcote, Victoria (Talent, 1965; Holloway and Neil, 1982) — especially those from the Mt Ida Formation — supports this age determination.

Mawson (1975) inferred a Pragian age for the upper part of the Tangerang Formation on the basis of an occurrence of the cheirurid trilobite *Crotalocephalides* at GR 626240.

ENVIRONMENT OF DEPOSITION

The undifferentiated part of the Tangerang Formation was probably deposited in a shallow water marine environment which was characterized by generally calm conditions with weak to moderate currents. The sporadic occurrence of coarse-grained sedarenites may indicate short periods of storm activity or slight fluctuations in the relative sea level.

The overall palaeocurrent trend for the Tangerang Formation in the Bungonia-Windellama area is northerly (005°, Fig. 5). The lower undifferentiated part of the

Fig. 4. Early Devonian (probably Lochkovian) fossils from the Tangerang Formation, Windellama district, New South Wales. **A**,**B**, *Pleurodictyum* sp. encrusting the brachiopod cf. *Nucleospira* with epifauna. Both external moulds of basal surface of colony, x3. **A**, AMf68594; **B**, AMf68595. Locality GR 652268. **C**,**D**, cf. *Lioharpes* sp., internal mould in dorsal view (**C**) and lateral view (**D**). AMf68596, both x2. Locality GR 647263. **E**,**F**, *?Crotalocephalus* sp. A, dorsal (**E**) and antero-lateral (**F**) view of internal mould of cranidium. AMf68597, both x1.5. Locality GR 648262. **G**, *?Crotalocephalus* sp. B, internal mould in dorsal view. AMf30029, x1.5. This specimen is from the C.F. Laseron collection and is labelled 'Windellama, N.S.W.' **H**, *?Acanthopyge (Lobopyge)* sp., dorsal view of latex cast of internal mould of cranidium. AMf68598, x8. Locality GR 648262. **I**, indeterminate proetid cranidium, dorsal view of internal mould. AMf68599, x5. Locality GR 648262.

formation exhibits a consistent north-north-easterly palaeocurrent trend (016°) whereas the upper part of the formation shows more variable trends with northerly (359°), westerly (270°) and south-southeasterly (153°) modes. The latter palaeocurrents are probably responsible for the lensoidal bedding and the interdigitation of the clastic lithotypes in this part of the formation. The abundance of pyroclastic flows and lava in the 'Lumley Park' area may represent the build-up of a non-marine volcanic pile which would have affected the palaeocurrent patterns.

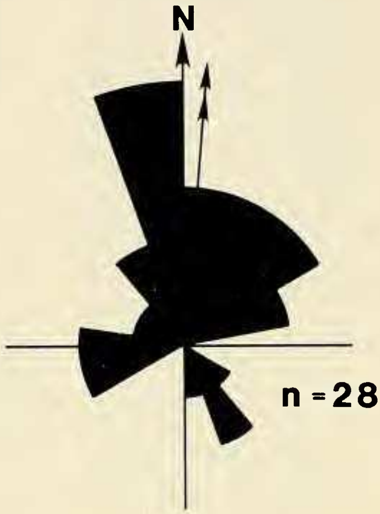


Fig. 5. Total palaeocurrent data from the Tangerang Formation in the Bungonia-Windellama area.

MARULAN BATHOLITH

The Marulan Batholith comprises a series of plutons which crop out discontinuously in a meridional belt extending over at least 60km from Windellama in the south to Bullio in the north. Various rock types have been described, including hybrid rocks (Osborne and Lovering, 1953) which O'Reilly (1972) has re-intepreted as contact metamorphic rocks produced by the intrusion of granitic rocks into silicic volcanics. Carr *et al.* (1981) mapped four plutons of the Marulan Batholith in the Bungonia area — the Springponds Granodiorite, Wylora Quartz Gabbro, Lumley Adamellite and Inverary Tonalite. K-Ar data for biotite separates from the granodiorite, quartz gabbro and adamellite indicate a mean age of emplacement of 398 Ma (Early Devonian) for the southern part of the Marulan Batholith (Carr *et al.*, 1980). Six plutons of the Marulan Batholith are recognized in the Bungonia-Windellama area. These include the four plutons described previously from Bungonia by Carr *et al.* (1981), together with the Torwood Granodiorite and Bogungra Microtonalite.

TORWOOD GRANODIORITE (new name)

The Torwood Granodiorite, which intrudes the Tangerang Formation and Bogungra Microtonalite in the central portion of the study area, is named after the property 'Torwood' (GR 645322) and has its type locality at GR 643321.

The granodiorite is a pale grey, leucocratic, medium- to coarse-grained hypidiomorphic granular rock composed of quartz, plagioclase, K-feldspar, hornblende and biotite. Fe-Ti oxides, rutile and zircon comprise the accessory phases whereas sericite, chlorite, uralite and prehnite are developed as secondary minerals. Plagioclase is the dominant mineral and it occurs as incipiently altered laths which have normal zoning from cores of An_{47} to rims of An_{26}. K-feldspar also shows extensive incipient alteration but hornblende and biotite have only minor replacement by secondary minerals.

BOGUNGRA MICROTONALITE (new name)

The Bogungra Microtonalite crops out as an elongate pluton in the central part of the study area and as a small apophysis at GR 614297. The intrusion exhibits obvious cross-cutting relationships with the surrounding sedimentary sequence (Fig. 1). The type locality is at GR 641295 and the intrusion is named after Bogungra Creek which traverses the southern margin of the pluton.

Hand specimens of the Bogungra Microtonalite are grey-green, leucocratic, holocrystalline and porphyritic with medium- to coarse-grained phenocrysts set in a very fine-grained quartzo-feldspathic groundmass. Plagioclase, hypersthene, augite, quartz and minor Fe-Ti oxides, biotite, zircon and apatite constitute the phenocrystic phases. The most abundant mineral is plagioclase and although a few phenocrysts show normal zoning from cores of An_{45} to rims of An_{17} most grains are andesine (An_{35-48}) in composition. Many of the plagioclase crystals show extensive sericitization and the pyroxenes are rimmed by hornblende and uralite. Quartz phenocrysts contain deep embayments and have recrystallized margins. Secondary minerals include prehnite, sericite, uralite and epidote.

Late Devonian Sedimentary Rocks

Naylor (1939) recorded a Late Devonian fauna from near the base of a quartz-rich sandstone and shale sequence which unconformably overlies the Tangerang Formation and Marulan Batholith. This unit displays a consistent shallow dip to the west (12°–20°) where it is truncated by the Yarralaw Fault. The sequence includes poorly bedded or massive sandstone and thinly interbedded sandstone and shale with common sedimentary structures such as ripple marks, cross-beds and scours. The sandstone, ranging from fine-grained and moderately sorted to coarse-grained and poorly sorted, is composed of quartz, fine-grained micaceous siltstone and chert rock fragments and rare feldspar and volcanic rock fragments set in a matrix of clay, microcrystalline quartz and iron oxide. It is classified as an immature sedarenite.

Post-Devonian Sedimentary Rocks

Numerous small poorly exposed outcrops of immature quartzarenite and poorly to moderately consolidated conglomerate, manganiferous grit, ferruginous shale, silcrete, laterite and ferricrete unconformably overlie the Early and Middle Palaeozoic rocks of the Bungonia-Windellama area. The outcrops of quartzarenite are lithologically similar to outcrops north of Bungonia (Carr *et al.*, 1981) and at Marulan South (Wass and Gould, 1969) and probably represent outliers of Permian strata of the Sydney Basin sequence. Early Tertiary fine- to very coarse-grained sandstone has been preserved beneath the Reevesdale Basalt near 'Lumley Park' (GR 678342) where it fills irregularities on the pre-basaltic landsurface. The sandstone is overlain by brown and black organic-rich clay which contains a rich and diverse microflora of the late Early to Middle Eocene *Proteacidites asperopolus* Zone (E. M. Truswell, pers. comm., 1985).

Reevesdale Basalt

The Late Eocene Reevesdale Basalt (Carr *et al.,* 1981) occurs as a series of discontinuous outcrops in the northern portion of the study area where it unconformably overlies older rocks and sediments. Drilling by North Broken Hill Pty Ltd has indicated that the basalt is up to 58.5m thick at GR 678342. The rock is an alkali-olivine basalt consisting of plagioclase (An_{62-48}), olivine, titaniferous augite, Fe-Ti oxides and accessory apatite. K-Ar dating by Wellman and McDougall (1974) indicates an age of 47.2 Ma (recalculated using the decay constants of Steiger and Jager, 1977). The basalt cropping out near 'Kooringaroo' is petrographically indistinguishable from the Reevesdale Basalt and as it has a K-Ar age of 45.4 Ma (recalculated from Wellman and McDougall, 1974) it may represent part of a related flow.

The numerous pisolitic red-brown bauxite deposits occurring between 'Aloes' and 'Bunburra' were probably derived from the Tertiary basalts by intense weathering. The pisolites (5-20mm) are grey when fresh and consist predominantly of goethite.

Dolerite. A small subcircular dolerite intrusion at GR 623229 may represent a volcanic pipe. The rock is medium-grained, holocrystalline and mesocratic with an intergranular texture and no evidence of flow structures. It is composed of zoned plagioclase (An_{65-29}), titaniferous augite, olivine and accessory Fe-Ti oxides and analcime, and is classified as an alkali olivine dolerite. The mineralogy of this dolerite is similar to the numerous dolerite dykes reported by Carr *et al.* (1981) from the Bungonia area and it is probably also related to the extrusion of the Eocene basalt.

Regional Structure

FOLDS

Tight to isoclinal folds are displayed in the Tallong Beds along the eastern margin of the study area. At locality GR 689317 medium- to large-scale isoclinal folds are present in a sequence of interbedded shale and chert. The limbs of these folds dip steeply to the west (approximately 85°), the axial planes trend north-northeast (average 030°) with a slight plunge (5°–10°) in the same direction. At locality GR 632228 moderate to tight north-northeast trending (028°) folds occurring in a quartzarenite-shale sequence have dips on the limbs ranging from 25° to 83°. Small-scale tight to isoclinal folds, showing weak bedding plane cleavage and pronounced thickening of fold hinges, are exhibited in the shale interbeds in this sequence. The axial planes of these small folds are subparallel to the larger folds, thus suggesting that they were all produced concurrently. Mawson (1975) described a series of folds with north-northeast trending axes in sedimentary units that she considered to be Silurian in age, but which are considered here to be part of the Ordovician Tallong Beds.

The fold style developed in the Tallong Beds in the study area is similar to that displayed in the unit at Bungonia (Carr *et al.*, 1981). At least one phase of folding of the Late Ordovician Tallong Beds occurred prior to the deposition of the Bungonia Limestone and Tangerang Formation and it was probably produced by the Late Ordovician-Early Silurian Benambran Orogeny.

Mawson (1975) noted broad gentle folds in the Early Devonian sequence cropping out near Windellama and these north-northeast trending folds can be traced northwards to the Bogungra Microtonalite (Fig. 1). These folds become tighter towards the Yarralaw Fault.

The consistent westerly dip of 25° to 40° displayed by the Tangerang Formation in the 'Brooklyn' -Bungonia area indicates that this sequence probably represents one limb of a broad regional fold (cf. Naylor, 1950). The uniformity in dip of the Tangerang Formation on both sides of the batholith suggest that the folding occurred during the Early Devonian Bowning Orogeny prior to the intrusion of the Marulan Batholith.

The Late Devonian sequence has a consistent shallow westerly dip of 12° to 20°.

FAULTS

The area studied is bounded on the west and south by the Yarralaw and Jacqua Faults respectively (Mawson, 1975). The north-northeast trending Yarralaw Fault separates an upthrown block of Late Silurian limestone and ferruginous shale in the west, from the downthrown block of Early Devonian Tangerang Formation in the east (Naylor, 1950; Mawson, 1975). The fault has a minimum vertical displacement of 2km — the thickness of the Tangerang Formation east of the fault. The northward extension of the Yarralaw Fault was mapped by Brunker and Offenberg (1968) from 'Kooringaroo' to the Hume Highway where it separates Late Devonian sedimentary strata (on the east) from undifferentiated Ordovician-Silurian sedimentary strata (on the west). Movement on the Yarralaw Fault is therefore post-Late Devonian and pre-Eocene.

The Late Ordovician-Early Devonian boundary in the study area is dissected by a number of small east-west faults (Fig. 1) which display elements of lateral, vertical and slight rotational movement. As these faults fail to offset the margins of the Bogungra Microtonalite they must be earliest Devonian in age, possibly associated with the Bowning Orogeny as suggested by Carr *et al.* (1980).

Discussion

The Late Ordovician Tallong Beds at Windellama show a primary petrographic association of interbedded fine-grained quartz-rich sandstone, slate and chert, and a tight to isoclinal fold style. The presence of classical Bouma sequences in the Tallong Beds indicates deposition by turbidity currents whereas the occurrence of radiolarian chert interbeds represents slower deposition. Similar petrographic and structural associations in the Tallong Beds have been reported from the Bungonia area by Carr *et al.* (1981). Thus the whole Tallong Bed sequence in the Bungonia-Windellama area represents quartz-rich distal flysch similar to that which accumulated throughout the southern Lachlan Fold Belt, i.e., an extension of Unit B of Crook *et al.* (1973). The character and palaeocurrent data exhibited by the Tallong Beds are consistent with deposition in a forearc basin as suggested by Cas *et al.* (1980). The tight folds in the Tallong Beds were produced in the latest Ordovician or earliest Silurian as a result of tectonic movements associated with the Benambran Orogeny.

The Bungonia-Windellama region remained deeply submerged after the Benambran folding as indicated by the graptolitic distal flysch of the Early Silurian 'Jerrara Series' (Naylor, 1936) 5km west of Bungonia. A major period of uplift in the Canberra-Quidong region (e.g. Wenlockian Quidongan Orogeny of Crook *et al.*, 1973) accounts for the uplift of the Late Ordovician and Early Silurian sequences to form the eastern edge of the Benambran Landmass proposed by Powell (in Veevers, 1984). The dextral transform motion suggested in Veevers (1984) for the eastern Australian continental margin during the Middle Silurian would have led to the development of a series of meridional horsts and grabens. The Late Silurian to Early Devonian shallow marine facies in the Bungonia-Windellama area accumulated on the eastern margin of the Wollondilly Tract where it abuts the South Coast High.

Late Silurian limestone and shale occur extensively in the Bungonia region (Carr *et al.*, 1981) where they overlie eroded Tallong Beds on the shallowly submerged edge of the South Coast High. The Bungonia Limestone contains a higher terrigenous component towards the south, suggesting that the Tallong Beds were emergent nearby, shedding abundant material into the area between 'Lumley Park' and Windellama. The Late Silurian shallow marine limestone and shale cropping out west of the Yarralaw Fault near Windellama (Mawson, 1975) is presumably a lateral equivalent of the lower part of the Bungonia Limestone. The Late Silurian shoreline is not exposed in the Windellama area but probably lies beneath the Tangerang Formation. The occurrence of *Spathognathodus* sp. cf. *S. remscheidensis* in both the Windellama Limestone Member and the upper limestone of the Bungonia Limestone (Jones *et al.*, 1981) suggests that these two earliest Devonian units are correlatives. Further evidence for such correlation is the occurrence of broadly similar trilobite faunas in both the litharenite near the base of the Tangerang Formation between 'Bunburra' and 'Aloes' and the upper shale of the Bungonia Limestone. Thus deposition of the Tangerang Formation commenced earlier south of Bungonia than north of Bungonia where limestone deposition remained dominant for some short time into the Early Devonian (see Jones *et al.*, 1984: fig. 7). Termination of limestone deposition in the Bungonia-Windellama region was due to the eruption of acid volcanics and swamping of the region with primary and reworked volcanic debris.

The Early Devonian Tangerang Formation overlies the Late Ordovician Tallong Beds in the 'Aloes' -Windellama area with a marked angular unconformity (Fig. 3) and the Brooklyn Conglomerate Member represents deposition during an erosive phase at the start of a Devonian marine transgression. The Tangerang Formation is composed of a shallow marine sequence of conglomerate, limestone, sublitharenite, volcaniclastic arenite and tuff. The increasing volcanic content in the 'Lumley Park' area is demonstrated by the occurrence of lapilli and fine airfall tuff, accretionary lapilli, dacitic agglomerate and lava as well as associated volcaniclastic sedimentary rocks. The lack of marine fauna in this area together with the occurrence of accretionary lapilli, fiamme and thick beds of coarse pyroclastic debris indicates that the 'Lumley Park' area may have represented a subaerial vent during the Early Devonian. Palaeocurrent analysis has revealed progressive changes during the deposition of the Tangerang Formation from dominant easterly and northerly trends in the lower part of the formation to more variable northerly, westerly and south-southeasterly current directions in the upper part of the formation. This probably reflects interruption of the northerly palaeocurrent system along the axis of the Wollondilly Tract by the emergence of the subaerial volcanic centre near 'Lumley Park'. The lack of deformation in the Tangerang Formation associated with the intrusion of the Marulan Batholith suggests that the formation was folded into a broad regional open fold prior to the intrusion of the Early Devonian batholith, i.e., the folding was probably associated with an early phase of the Bowning Orogeny which produced the Snowy Mountains Uplift (Veevers, 1984).

Six phases of the Marulan Batholith have been mapped in the Bungonia-Windellama area and two of these bodies are confined to the Windellama region. The Bogungra Microtonalite is porphyritic, and has a very thin and low-grade metamorphic aureole, which accords with rapid cooling at a shallow depth. The microtonalite is intruded by the Torwood Granodiorite which grades northwards into the Lumley Adamellite of Carr *et al.* (1981). Intrusion of the southern portion of the Marulan Batholith (398 Ma, Carr *et al.*, 1981) probably occurred during the Bowning Orogeny.

The Bungonia-Windellama area presumably became emergent after the Bowning Orogeny as there is no record of Middle Devonian deposition. Late Devonian sandstone and shale unconformably overlie the Tangerang Formation and Marulan Batholith, and were deposited in a shallow marine to terrestrial environment (Naylor, 1939; Carr *et al.*, 1981). Post-Late Devonian movement occurred on the Yarralaw and Jacqua Faults preserving the Tangerang Formation and Late Devonian sequence as a downthrown westerly-dipping block.

Coarse-grained quartz-rich sandstone occurring unconformably above the Devonian rocks probably represents outliers of the Permian Sydney Basin sequence as noted by Wass and Gould (1969) in the Marulan area. The Reevesdale Basalt forms part of the Late Eocene Nerriga Province (Wellman and McDougall, 1974). The basalt flowed onto an irregular Early Eocene land surface and preserved an excellent flora in valley-fill sediments beneath the flow. A small alkali olivine dolerite body near 'Bunburra' is presumably an intrusive equivalent to the Tertiary basalts and may represent a feeder pipe. Small localized outcrops of Tertiary sedimentary units present in the Bungonia-Windellama area include manganiferous grit, ferruginous shale, pyrolusite-cemented quartzarenite, bauxite, ferricrete and silcrete.

ACKNOWLEDGEMENTS

We thank J. F. Benison, S. H. Williams and all the property owners in the Bungonia-Windellama area for their assistance and cooperation. Studies of Devonian fossils by A. J. Wright have been supported by grants from the ARGS and the University of Wollongong. We also gratefully acknowledge the continued help and support of the technical and clerical staff in the Department of Geology at the University of Wollongong.

References

BRUNKER, R. L., and OFFENBERG, A. C., (compilers), 1968. — Goulburn 1:250,000 geological series, sheet SI 55-12. *Geol. Surv. N.S.W.*, Sydney.

CAMPBELL, K. S. W., 1967. — Henryhouse trilobites. *Bull. geol. Surv. Okla.* 112.

——, 1977. — Trilobites of the Haragan, Bois d'Arc and Frisco Formations (Early Devonian), Arbuckle Mountains region, Oklahoma. *Bull. geol. Surv. Okla.* 123.

CARNE, J. E., and JONES, L. J., 1919. — The limestone deposits of New South Wales. *N.S.W. geol. Surv., Miner. Resour.* 25.

CARR, P. F., JONES, B. G., KANTSLER, A. J., MOORE, P. S., and COOK, A. C., 1981. — The geology of the Bungonia district, New South Wales. *Proc. Linn. Soc. N.S.W.* 104: 229-244.

——, ——, and WRIGHT, A. J., 1980. — Dating of rocks from the Bungonia district, New South Wales. *Proc. Linn. Soc. N.S.W.* 104: 113-117.

CAS, R. A. F., POWELL, C. MCA., and CROOK, K. A. W., 1980. — Ordovician palaeogeography of the Lachlan Fold Belt: a modern analogue and tectonic constraints. *J. geol. Soc. Aust.* 27: 19-31.

CHLUPAC, I., 1977. — The phacopid trilobites of the Silurian and Devonian of Czechoslovakia. *Rozp. ustred. Ust. Geol.* 43.

CROOK, K. A. W., BEIN, J., HUGHES, R. J., and SCOTT, P. A., 1973. — Ordovician and Silurian history of the southeastern part of the Lachlan Geosyncline. *J. geol. Soc. Aust.* 20: 113-138.

ELLIS, R., HAWKINS, L., HAWKINS, R., JAMES, J., MIDDLETON, G., NURSE, B., and WELLINGS, G., (eds), 1972. — *Bungonia Caves*. Sydney: Sydney Speleological Society.

FELTON, E. A., and HULEATT, M. B., 1977. — Geology of the Braidwood 1:100,000 Sheet 8827. *Geol. Surv. N.S.W.*, Sydney.

FOLK, R. L., 1974. — *Petrology of sedimentary rocks*. Austin, Texas: Hemphill Publ. Co.

GARRETTY, M. D., 1937. — Geological notes on the country between the Yass and Shoalhaven Rivers. *J. Proc. Roy. Soc. N.S.W.* 70: 364-374.

HOLLOWAY, D. J., 1980. — Middle Silurian trilobites from Arkansas and Oklahoma, U.S.A. *Palaeontographica* 170A: 1-85.

——, and NEIL, J. V., 1982. — Trilobites from the Mount Ida Formation (Late Silurian-Early Devonian), Victoria. *Proc. Roy. Soc. Vict.* 94: 133-154.

JONES, B. G., CARR, P. F., and HALL, C. G., 1984. — The Early Devonian Tangerang Formation of the Marulan-Windellama region, N.S.W. — definition and palaeoenvironmental significance. *Aust. J. Earth Sci.* 31: 75-90.

——, ——, and WRIGHT, A. J., 1981. — Silurian and Early Devonian geochronology — a reappraisal, with new evidence from the Bungonia Limestone. *Alcheringa* 5: 197-207.

MAWSON, R., 1975. — The geology of the Windellama area, New South Wales. *J. Proc. Roy. Soc. N.S.W.* 108: 29-36.

NAYLOR, G. F. K., 1935. — Note on the geology of the Goulburn District, with special reference to Palaeozoic stratigraphy. *J. Proc. Roy. Soc. N.S.W.* 69: 75-85.

——, 1936. — The Palaeozoic sediments near Bungonia: their field relations and graptolite fauna. *J. Proc. Roy. Soc. N.S.W.* 69: 123-134.

——, 1939. — The age of the Marulan Batholith. *J. Proc. Roy. Soc. N.S.W.* 73: 82-85.

——, 1950. — A further contribution to the geology of the Goulburn district, N.S.W. *J. Proc. Roy. Soc. N.S.W.* 83: 279-287.

O'REILLY, S. Y., 1972. — Petrology and stratigraphy of the Brayton district, New South Wales. *Proc. Linn. Soc. N.S.W.* 96: 282-296.

OSBORNE, G. D., 1931. — The contact metamorphism and related phenomena in the neighbourhood of Marulan, New South Wales. Part I. The quartz-monzonite—limestone contact. *Geol. Mag.* 69: 289-314.

——, 1949. — Contributions to the study of the Marulan Batholith. Part I. The contaminated granodiorites of South Marulan and Marulan Creek. *J. Proc. Roy. Soc. N.S.W.* 82: 116-128.

——, and LOVERING, J. F., 1953. — Contributions to a study of the Marulan Batholith. Part II. The granodiorite-quartz porphyrite hybrids. *J. Proc. Roy. Soc. N.S.W.* 86: 108-118.

PICKETT, J. W., 1970. — Macrofossils from the 'Windellama' limestone. *N.S.W. geol. Surv., Palaeontol. Rep., No. 1970/17* (unpubl.).

——, 1972. — Marine fossils from sandstones at Windellama. *N.S.W. geol. Surv., Palaeontol. Rep., No. 1972/2* (unpubl.).

——, and HULEATT, M. B., 1971. — Age of the Windellama Limestone. *Quart. Notes N.S.W. geol. Surv.* 2: 1-4.

PRATT, B. T., 1964. — The origin of Bungonia Caves. *J. Mining geol. Soc. Uni. N.S.W.* 2: 44-51.

SHERRARD, K., 1949. — Graptolites from Tallong and the Shoalhaven Gorge, New South Wales. *Proc. Linn. Soc. N.S.W.* 74: 62-68.

——, 1954. — The assemblages of graptolites in New South Wales. *J. Proc. Roy. Soc. N.S.W.* 87: 73-101.

——, 1962. — Further notes on assemblages of graptolites in New South Wales. *J. Proc. Roy. Soc. N.S.W.* 95: 167-178.

SHERWIN, L., 1972. — Ordovician graptolite-conodont associations from the Goulburn district. *Quart. Notes N.S.W. geol. Surv.* 6: 3-5.

STEIGER, R. H., and JAGER, E., 1977. — Subcommission on geochronology: convention on the use of decay constants in geo- and cosmochronology. *Earth. Planet. Sci. Lett.* 36: 359-362.

TALENT, J. A., 1965. — The Silurian and Early Devonian faunas of the Heathcote district, Victoria. *Mem. geol. Surv. Vict.* 26.

VEEVERS, J. J., (ed.), 1984. — *Phanerozoic earth history of Australia.* Oxford: Clarendon Press.

WASS, R. E., and GOULD, I. G., 1969. — Permian faunas and sediments from the South Marulan district, New South Wales. *Proc. Linn. Soc. N.S.W.* 93: 212-226.

WELLMAN, P., and MCDOUGALL, I., 1974. — Potassium—argon ages on the Cainozoic volcanic rocks of New South Wales. *J. geol. Soc. Aust.* 21: 247-272.

WOOLNOUGH, W. G., 1909. — The general geology of Marulan and Tallong, N.S.W. *Proc. Linn. Soc. N.S.W.* 34: 546-553.

APPENDIX

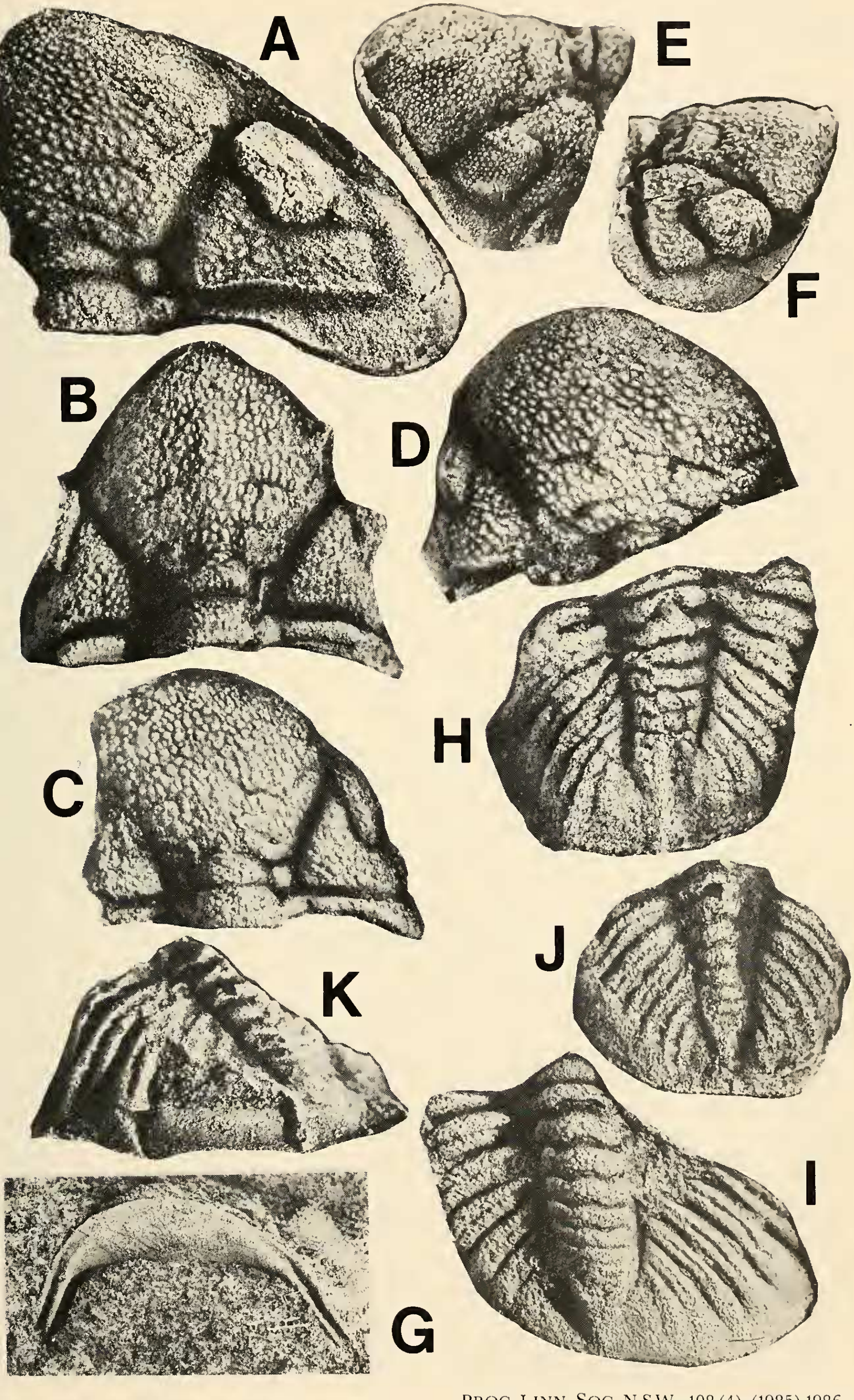
TAXONOMIC PALAEONTOLOGY

Phylum ARTHROPODA
Order PHACOPIDA Struve, 1959
Family PHACOPIDAE Hawle & Corda, 1847
Genus ANANASPIS Campbell, 1967

Type Species. *Phacops fecundus* Barrande, 1846

Remarks. This genus has been discussed by Campbell (1967), Chlupac (1977) and Holloway (1980). The first two authors are followed herein in assigning generic-level taxonomic importance to the vincular furrow, which in this genus is anteriorly shallow to absent. Other important characters include: pronounced 2s and 3s glabellar furrows; tubercles and granules on the glabella; and distinct interpleural furrows on the pygidium. Holloway (1980) suggested that, as the depth of the anterior part of the vincular furrow is variable in other phacopids, it is impossible to differentiate between *Ananaspis* and *Paciphacops (Paciphacops)* Maximova (1972) on that criterion; if so, perforated glabellar tubercles in *P. (Paciphacops)* may be the only important generic distinction between *Ananaspis* and *P. (Paciphacops).* Two other subgenera of *Paciphacops* — *P. (Viaphacops)*

Fig. 6. Anaspis ekphyma sp. nov. All from the Early Devonian (probably Lochkovian) Tangerang Formation, Windellama district, New South Wales. Locality GR 648262. **A**, AMf68600, holotype cephalon, dorsal view, x4. **B**, AMf68601, latex cast of paratype cephalon, dorsal view, x4. **C**, AMf68602, latex cast of paratype cephalon, dorsal view, x4. **D**, AMf68603, latex cast of paratype cephalon, dorsal view, x4. **E**, AMf68604, latex cast of paratype cephalon, lateral view, x4. **F**, AMf68605, paratype cephalon, lateral view, x3. **G**, AMf68606, latex cast of paratype showing doublure and vincular furrow, x3. **H**, AMf68607, latex cast of paratype pygidium, x4. **I**, AMf68608, latex cast of paratype pygidium, x4. **J**, AMf68609, latex cast of paratype pygidium, x 4. **K**, AMf68610, lateral view of mould of paratype pygidium showing doublure, x4 approx.


A
B
C
D
E
F
G
H
I
J
K

Maximova (1972) and *P. (Angulophacops)* Maximova (1978) — differ from *Ananaspis* in a number of important aspects.

Ananaspis ekphyma sp. nov.
Fig. 6**A-K**

Types. AMf68600, holotype; AMf68601-68610, paratypes. All from the Tangerang Formation, grid reference 648262, Kooringaroo 8828-II-S 1:25,000 sheet. Early Devonian (probably Lochkovian). All material housed in the Australian Museum, College Street, Sydney.

Diagnosis. *Ananaspis* with long (exsag.) postocular area; long lateral border furrow; short genal spine; eye with up to 17 files with about 9 lenses per file; relatively numerous glabellar tubercles as well as only sparse granules; long (tr.) lateral occipital lobe; vincular furrows weakly notched laterally.

Derivation of Name. From the Greek word ekphyma, meaning an eruption of pimples.

Description. Outline of cephalon elongate to transversely semi-oval. Prominent glabella globose, expanding forward at about 60°; maximum width at anterior border furrow, at about mid-length; anterior margin overhanging narrow furrow. Axial furrows weak across wide (sag.) occipital ring (producing a wide (tr.) lateral occipital lobe), diverging immediately in front on 1s; lateral extremities of 1p almost completely isolated by short (exsag.) furrows. 1s furrows deep laterally, reaching almost to mid-line, transverse laterally, but adaxial portions anteriorly directed at low angle; 2s furrows gently convex forward, shorter and shallower than 1s; 3s furrows gently convex forward in adaxial portion, making slight angle with 2s, and lateral portion (anterior ramus) shorter and trending anteriorly towards axial furrow. Eye with up to (approx.) 17 files with about 9 lenses per file; anterior end close to axial furrow and level with anterior end of 3s; posterior end level with anterior end of 2s, well anterior of posterior border furrow. Palpebral lobes below level of glabella, with well-defined furrow running across lobe and down around base of eye to meet broad anteriorly weakening lateral furrow. Posterior limb narrows lateral to occipital ring, then widens abruptly level with the base of the eye, and the broad margin thus formed extends around genal angle with short spine, narrowing forward to the level of the front of the eye. Deep and rounded posterior border furrow turns inside genal angle at about 90°, becoming shallower and wider anteriorly, giving rise to slightly upturned margin beneath overhanging glabella. Margin bears granules on both dorsal and ventral surfaces; doublure wide anteriorly, vincular furrow not developed anteriorly, and only weakly notched. Tubercles developed abundantly on glabella, rings, cheeks inside border furrow, palpebral ridge and posterior limb. Granules are also developed sparsely on the glabella, where ornament becomes finer anteriorly.

Hypostome and thorax not found.

Pygidium transversely semi-oval, with marked facets accounting for ½ of width of pleural fields. 8(?9) axial rings plus a terminal piece; 6 ribs, with interpleural furrows deeper and longer than pleural furrows, both being slightly curved. Crests of axial rings (slightly W-shaped) and ribs bear low tubercles which reduce in size laterally to granules on the wide margin; doublure wide.

Remarks. This *Ananaspis* material is tectonically deformed so morphological features such as glabellar form must be assumed to be not in their pristine condition. Further, the material is somewhat silicified. Nevertheless, *A. ekphyma* sp. nov. is quite different from other species assigned to *Ananaspis*, either in the restricted sense used by Campbell (1967) and Chlupac (1977) or in the wider interpretation followed by Holloway (1980). In particular, the species is distinct in its glabellar prosopon which includes close-set and numerous tubercles and only very sparse granules, in which it resembles *Paciphacops (Viaphacops)*. From the Australian species *Phacops serratus* Foerste, 1888; *Phacops crosslei* Etheridge and Mitchell, 1896; and *Phacops latigenalis* Etheridge and Mitchell, 1896, *A. ekphyma* differs in having anteriorly no trace of the vincular furrow. From species referred to *Ananaspis* by Campbell (1967, 1977) and Chlupac (1977), *A. ekphyma* differs in one or more of the following characters: the anteriorly placed eye; the long lateral border furrow; and the abundance of glabellar tubercles and rarity of glabellar granules. Material assigned to *Ananaspis f. fecunda* Barrande, 1846 has eyes placed anteriorly as in *A. ekphyma*. The dimorphism in eye development discussed by Campbell (1977) has not been observed in the Windellama material, in which the eyes are very poorly preserved. Holloway (1980) noted that '*Ananaspis* is presently known from the Late Llandovery to the Ludlow'; therefore the Windellama species considerably extends the known range of *Ananaspis*. Holloway and Neil (1982) assigned to *Ananaspis* the species *Phacops claviger* Haas, 1969 from the Pragian Wenban Limestone of Nevada; the assignment is not followed here. *A. ekphyma* n. sp. thus appears to be the first described *Ananaspis* from Australia and also the youngest known species of the genus.

This species is associated with: *Pleurodictyum* sp.; cf. *Nucleospira* sp., indeterminate rhynchonellids; ?*Crotalocephalus* sp. A, ?*Acanthopyge (Lobopyge)* sp., a proetid, indeterminate scutelluids, odontopleurids; fenestellids and favositid corals.